IS 7396-4 (1983): Criteria for Hydraulic Design of Surge Tanks, Part 4: Multiple Surge Tanks [WRD 14: Water Conductor Systems]

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Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF SURGE TANKS

PART 4 MULTIPLE SURGE TANKS

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
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CRITERIA FOR HYDRAULIC DESIGN OF SURGE TANKS

PART 4 MULTIPLE SURGE TANKS

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(*Continued on page* 12)

Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF SURGE TANKS

PART 4 MULTIPLE SURGE TANKS

0. FOREWORD

0.1 This Indian Standard (Part 4) was adopted by the Indian Standards Institution on 27 December 1983, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 This standard relates to design of multiple surge tanks, provided when the water conductor system has two or more shafts, with free surface upstream of power station (*see* Fig. 1). Multiple surge tanks occur usually in the following cases:

a) The conduit conveying water from the main source to the power house may admit water enroute from other sources, for which suitable shafts (vertical or inclined) will be necessary. These will serve as components of multiple surge system.

b) Where the head race tunnel is required to pass in the form of a syphon, a shaft may be necessary to avoid air locks. Such a shaft can form a component of multiple surge system.

c) When the capacity of the existing power station is proposed to be increased and it is not possible to increase the capacity of the existing surge tank, one or more additional surge tanks at suitable economical places may be provided.

d) Sometimes construction conveniences requires vertical construction shaft which can be utilized ultimately as part of the multiple surge tank system.

0.3 This standard forms part of a series of Indian Standards on surge tanks. Other standards in the series are as follows:

IS : 7396 Criteria for hydraulic design of surge tanks:

(Part 1)-1974 Simple, restricted orifice and differential surge tanks

(Part 2)-1975 Tail race surge tanks

(Part 3) Special surge tanks (*under preparation*)

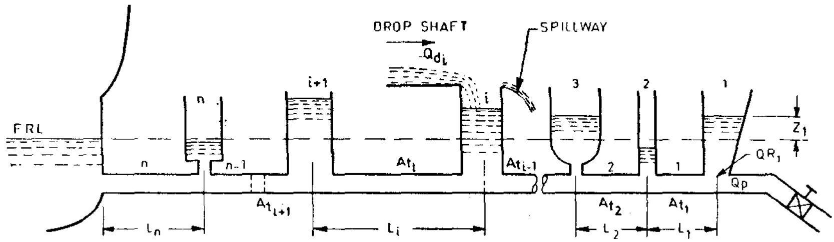

FIG. 1 SYSTEM OF MULTIPLE SURGE TANKS AND DROP SHAFTS

1. SCOPE

1.1 This standard (Part 4) lays down the criteria for the hydraulic design of more than one surge tank on the water conductor system upstream of the turbine.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions given in IS : 7396 (Part 1)-1974* shall apply.

3. NOTATIONS

3.1 For the purpose of this standard, the following notations shall have the meanings indicated against each:

A_{s_1}, A_{s_2} .... $A_{s_{n-1}}$, A_{s_n}	Horizontal cross sectional areas of surge tanks No. 1, 2 ...... $n-1$, n respectively
A_{t_1}, A_{t_2} .... $A_{t_{n-1}}$, A_{t_n}	Cross-sectional areas of tunnels No. 1, 2 ...... $n-1$, n preceding the surge tanks respectively
A_{th_1}, A_{th_2} .... $A_{th_{n-1}}$, A_{th_n}	Thoma's areas of surge tanks No. 1, 2 ...... $n-1$, n respectively
L_1, L_2 .... L_{n-1}, L_n	Lengths of tunnels No. 1, 2 ...... $n-1$, n respectively
L_{t_1}, L_{t_2} .... $L_{t_{n-1}}$, L_{t_n}	Lengths of tail race tunnels No. 1, 2 ...... $n-1$, n respectively
D_1, D_2 .... D_{n-1}, D_n	Equivalent diameters of tunnels No. 1, 2 ...... $n-1$, n respectively
V_{o_1}, V_{o_2} .... $V_{o_{n-1}}$, V_{o_n}	Steady state initial velocities in tunnels of lengths L_1, L_2, L_{n-1}, L_n respectively

*Criteria for hydraulic design of surge tanks: Part 1 Simple, restricted orifice and differential surge tanks.

$V_1, V_2 \ldots\ldots\ldots V_{n-1}, V_n$ — Velocities at any instant of time in the tunnels No. 1, 2 ...... $n - 1$, n respectively

$n_1, n_2 \ldots\ldots\ldots n_n$ — $\frac{A_{s_1}}{A_{th_1}}, \frac{A_{s_2}}{A_{th_2}} \ldots\ldots \frac{A_{s_n}}{A_{th_n}}$ respectively

$z_1, z_2 \ldots\ldots\ldots z_n$ — Water levels in surge tanks No. 1, 2 ...... n respectively measured positive above reservoir level

$Q_1, Q_2 \ldots\ldots\ldots Q_n$ — Discharges passing through tunnels No. 1, 2 ...... respectively

Q_{d_i} — Discharge falling into drop shaft, namely, ith surge tank

Q_p — Discharge in penstocks

$\triangle z_1, \triangle z_2 \ldots\ldots\ldots \triangle z_n$ — The positive rises in water levels in surge tanks No. 1, 2 ...... n respectively in short intervals of time $\triangle T$

$\triangle Q_1, \triangle Q_2 \ldots\ldots\ldots \triangle Q_n$ — The changes in discharge in tunnels No. 1, 2 ...... n respectively in short intervals of time $\triangle T$

$QR_1, QR_2 \ldots\ldots\ldots QR_n$ — Discharges through restricted orifices in surge tanks No. 1, 2 ...... n respectively

$R_1, R_2 \ldots\ldots\ldots R_n$ — Co-efficients of resistance in orifices of surge tanks No. 1, 2 ...... n respectively:

$$R = \frac{\text{head loss in orifice}}{(\text{discharge passing through the orifice})^2}$$

$A_{s_1}g, A_{s_2}g \ldots\ldots\ldots A_{s_n}g$ — Areas of surge tanks No. 1, 2 ...... n respectively at expansion galleries

$\beta_1, \beta_2 \ldots\ldots\ldots \beta_{n-1}, \beta_n$ — Co-efficients of hydraulic losses of tunnels No. 1, 2 ...... n respectively

K — Ratio of total power generated by the station to that of the grid.

4. DATA REQUIRED

4.1 The data required for the design of simple surge tanks, as given in IS : 7396 (Part 1)-1974*, shall be required for this part also for each surge tank and drop shaft.

4.2 At the time of design of surge systems, the designers should ascertain whether construction shafts, drop shafts are envisaged enroute and if so their dimensions and locations should be indicated. This shall have important bearing on the design of overall surge system.

5. ANALYSIS

5.1 General — When there are several shafts, the oscillations of each of the shafts get superimposed and interlinked in a complicated way. The influence of the nearest shaft is in general greater and therefore it is the period in relation to the nearest shaft that is more pronounced. The ratio between two successive maxima in any shaft is a measure of the dampening of the oscillations by the nearest shaft.

5.2 Procedure — In a system of multiple surge tanks, the continuity equation is developed at the junction of each surge tank with head race tunnel in a similar fashion as that for single surge tank [*see* IS : 7396 (Part 1)-1974*]. Dynamic (equilibrium) equation for each tunnel preceding the surge tanks is developed. In framing the dynamic equation, the surge tank preceding the tunnel acts as a reservoir, as in the case of single surge tank. A series of *n* number of surge tanks is shown in Fig. 1 and equations relating to this system are given in Appendix A.

5.2.1 The analysis for tail race tunnel multiple surge tanks may be carried out on similar lines as for head race tunnel (*see* Fig. 2).

6. DESIGN

6.1 The multiple surge tank system should be designed to withstand the worst conditions for minimum and maximum surge as specified in IS : 7396 (Part 1)-1974*.

6.1.1 The criterion to provide spillover in each of these shafts would be the same as specified in **6.1.1** of IS : 7396 (Part 1)-1974*.

*Criteria for hydraulic design of surge tanks: Part 1 Simple, restricted orifice and differential surge tanks.

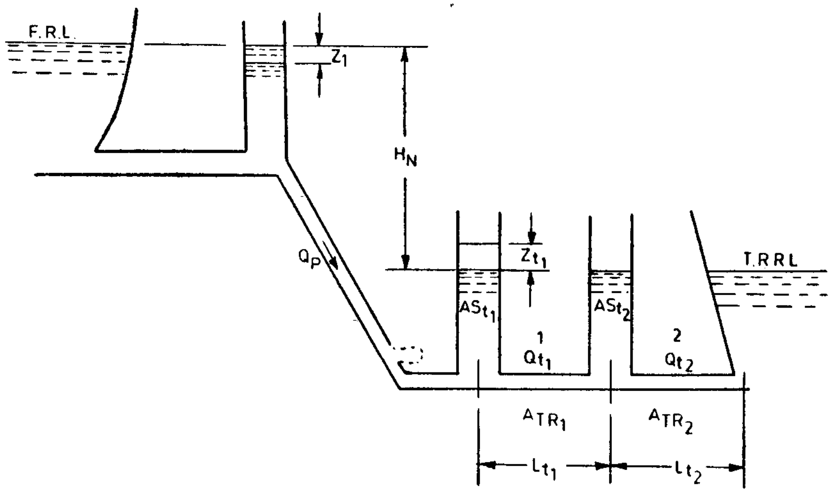

FIG. 2 MULTIPLE SURGE TANKS ON TAIL RACE TUNNEL

6.2 Friction Factor

6.2.1 *Manning's Formula* — The formula is given below:

$$h_f = \frac{V^2 N^2 L}{R^{4/3}}$$

where

h_f = head loss due to friction, in metres;

V = velocity of flow in the tunnel, in metres/second;

N = rugosity coefficient;

L = length of the tunnel, in metres; and

R = hydraulic radius, which is area/wetted perimeter, in metres.

6.2.1.1 For concrete-lined tunnels, the value of N varies from 0·012 to 0·014.

6.2.1.2 For unlined tunnels, the value of N depends on the nature of rock and the quality of trimming. Recommended values of N for various rock surface conditions are given below:

Surface Characteristic	*Value of N*	
	Min	*Max*
Very rough	0·04	0·06
Surface trimmed	0·025	0·035
Surface trimmed and invert concreted	0·020	0·030

6.2.1.3 The values of β_1, β_2 ... β_n may be determined from the following equations:

$$\beta_1 V_1^2 = \frac{V_1^2 N^2 L}{R^{4/3}} + \text{other losses in the tunnel system}$$

....

....

$$\beta_n V_n^2 = \frac{V_n^2 N^2 L_n}{R_n^{4/3}}$$

6.2.2 *Darcy-Weisbach Formula* — The formula is given below:

$$h_f = \frac{fL V^2}{2gD}$$

where

h_f = friction head loss, in metres;
f = friction coefficient;
L = length of the tunnel, in m;
V = velocity of flow in the tunnel, in m/s;
g = acceleration due to gravity, in m/s; and
D = diameter of the tunnel, in m.

6.2.2.1 The maximum, minimum and average values of friction coefficient may be taken from IS : 4880 (Part 3)-1976*. The values of β_1, β_2 ... β_n may be determined from the following equations:

$$\beta_1 V_1^2 = \frac{f_1 L_1 V_1^2}{2gD_1} + \text{other losses in the tunnel system}$$

$$\beta_2 V_2^2 = \frac{f_2 L_2 V_2^2}{2gD_2} + \text{other losses in the tunnel system}$$

....

....

$$\beta_n V_n^2 = \frac{f_n L_n V_n^2}{2gD_n} + \text{other losses in the tunnel system}$$

6.2.2.2 As the minimum coefficient gives the worst upsurge while the maximum coefficient gives the worst downsurge, these values shall be used for relevant conditions. In case of combination of load variations,

*Code of practice for design of tunnels conveying water: Part 3 Hydraulic design (*first revision*).

both the values of the coefficient shall be taken into account and the one which gives the worst condition shall be adopted. For calculating the worst upsurge, the maximum reservoir level should be considered whereas for the worst downsurge, the minimum reservoir level should be taken.

6.3 Area of Surge Tank — To ensure stability of the surge tank, the following equations shall be satisfied:

$$n_1 \geqslant 1$$
$$A_{s_1} \geqslant A_{th_1}$$

where

A_{th_1} is given by the following:

$$A_{th_1} = \frac{V_{01}^2 L_1 A_{t1}}{2g\beta_1, V_{01}^2 (H_{01} - \beta_1 V_{01}^2)}$$

where

H_{01} the gross head measured from the surge tank No. 2 in the steady state condition.

NOTE — The stability of the system is governed by the first tank (nearest to the power house).

6.3.1 In case there is an intermediate drop shaft enroute, the critical area of the surge tank shall be corrected to take into account the effect of additional discharge from the drop shaft as given below:

$$A_{th_1} (e) = A_{th_1} \frac{1}{1 - \frac{Q_{d_1}}{Q} \times \frac{L_1}{L}}$$

where

Q = total discharge,

Q_{d_1} = drop shaft discharge,

L_1 = length of tunnel from reservoir up to the drop shaft, and

L = total length of tunnel from reservoir up to the surge shaft.

NOTE — This formula provides only the guidelines and full stability analysis need to be carried out.

6.3.2 If the surge tank level of tank No. 2 is to vary over a large range, A_{th_1} may vary considerably for this range of surge tank level. In such cases, several trials shall be made to calculate A_{th_1} and the maximum A_{th_1} adopted.

6.3.3 If it can be ensured that the power station is to always operate in grid, the stabilizing effect of the grid may be taken into account and the area of surge shaft No. 1 (A_{s_1}) may be calculated using the formula:

$$A_{s_1} = A_{th_1} [1 - 1{\cdot}5 (1 - K)]$$

6.4 Factor of Safety — The area of the surge tank obtained from **6.3** gives the minimum area. Factor of safety shall apply as contained in IS : 7396 (Part 1)-1974*.

6.5 The extreme water levels in the surge tanks for the conditions enumerated in **6.1** can be determined by solving the equations given in Appendix A, preferably by computer.

NOTE 1 — Graphical method cannot be applied when there are more than two shafts.

NOTE 2 — It would be desirable to check the computer results in a hydraulic model.

NOTE 3 — In the case of drop shafts, however hydraulic model experiments have to be carried out to ensure that air does not enter into the tunnel.

6.6 Height of Surge Tanks — Provisions pertaining to the height of the surge tanks given in IS : 7396 (Part 1)-1974* shall apply to this part also.

APPENDIX A

(*Clauses* 5.2 *and* 6.5)

CONTINUITY AND DYNAMIC EQUATIONS FOR MULTIPLE SURGE TANK SYSTEM

$$\frac{\Delta Z_1}{\Delta T} = \frac{Q_1 - Q_p}{A_{s_1}}$$

$$\frac{\Delta Q_1}{\Delta T} = (Z_2 - Z_1 - \beta_1 \mid Q_1 \mid Q_1 - R_1 \mid QR_1 \mid QR_1) \; \frac{A_{t_1}}{L_1} - g$$

$$\frac{\Delta Z_2}{\Delta T} = \frac{Q_2 - Q_1}{A_{s_2}}$$

*Criteria for hydraulic design of surge tanks: Part 1 Simple, restricted orifice and differential surge tanks.

$$\frac{\Delta Q_2}{\Delta T} = (Z_3 - Z_2 - \beta_2 \mid Q_2 \mid Q_2 - R_2 \mid QR_2 \mid QR_2) \frac{A_{t_2}}{L_2} g$$

... ...

... ...

$$\frac{\Delta Z_i}{\Delta T} = \frac{Q_i \pm Q_{d_i} - Q_{i-1}}{A_{s_i}}$$

NOTE — ' + ' sign to be used for drop shaft and ' − ' to be used for spilling shaft.

$$\frac{\Delta Q_i}{\Delta T} = (Z_{i+1} - Z_i - \beta_i \mid Q_i \mid Q_i - R_i \mid QR_i \mid QR_i) \frac{A_{t_i}}{L_i} g$$

... ...

... ...

$$\frac{\Delta Z_n}{\Delta T} = \frac{Q_n - Q_{n-1}}{A_{s_n}}$$

$$\frac{\Delta Q_n}{\Delta T} = (- Z_n - \beta_n \mid Q_n \mid Q_n - R_n \mid QR_n \mid QR_n) \frac{A_{t_n}}{L_n} g$$

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INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	st

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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